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ACTIVE FIN ROLL STABILIZATION EFFECTIVENESS ON A 65' TORPEDO RE--ETC(U)  
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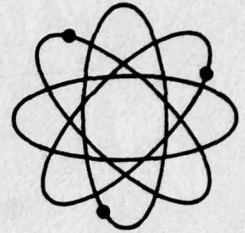


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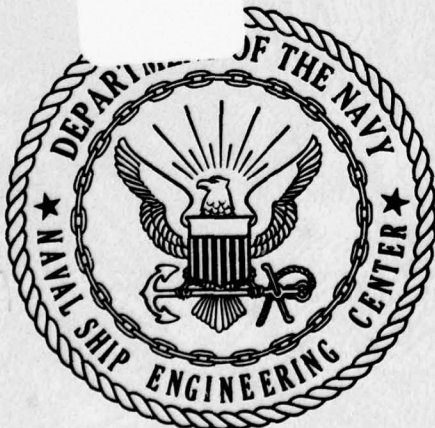
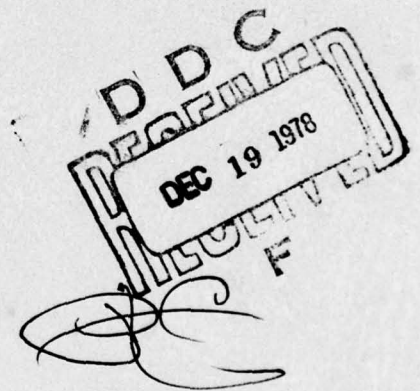
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ACTIVE FIN ROLL STABILIZATION  
EFFECTIVENESS ON A 65'  
TORPEDO RETRIEVER BOAT (TRB)

OCTOBER 1975

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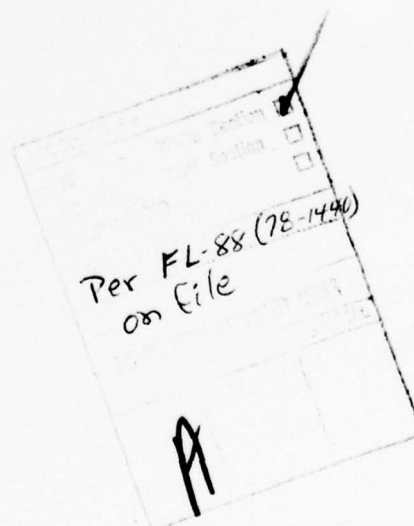
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## INTRODUCTION

Recent developments in weapons technology and the changing nature in the use of such weapons allow small craft to be configured as economical solutions for some applications heretofore accomplished with much larger ships. It follows then, that the designers of weapons and small craft will have to pay particular attention to better interfacing of the two systems. Since most small combatant craft are basically weapons platforms and will operate in open water, a major consideration will have to be given to reducing the rigid body motions specifically the pitch and roll motions of the craft, and vertical accelerations of the craft-weapon system. Normally, the longitudinal and transverse accelerations can be ignored due to the small magnitudes involved. Two approaches to stabilization can be employed, stabilize the weapon mount itself, and stabilize the vessel. Good design practice must consider both methods. To omit consideration of craft stabilization would be neglecting the important aspect of crew efficiency which, in the final analysis, determines the mission effectiveness. To obtain 100% attenuation of craft motions and accelerations in open water is impossible from a practical engineering point of view. Therefore, both vessel and weapon mount stabilization should be considered.

It is recognized by craft designers that round bottom small craft are subject to large roll excursions for many operational conditions and, as such, can benefit greatly by the addition of active fin roll stabilizer devices. These craft motions are large enough that the resulting top speed loss due to added appendage drag or increased displacement is a welcome trade-off for the added stability. The appendage drag can be reduced by utilizing a retractable fin roll stabilizer design. Consideration has to be given to stabilizing the other basic hull form, that of the vee-bottom, hard chine configuration. With this hull form, the craft is generally intended to be a planing hull with high speed capability. High speed/hard chine craft are inherently more stable than round bilge craft due to high hydrodynamic lifting forces and large roll damping coefficients resulting from chine shape. Still, all operations are not conducted at flank speed (most stable condition in roll for hard chine craft) so it is conceivable that for certain conditions and circumstances roll stabilizing devices might be employed at the lower speeds where roll motions could be excessive.

Since limited information exists on the effectiveness of anti-roll devices as applied to high speed/hard chine craft, a study was conducted by Naval Ship Engineering Center, Norfolk Division (NSND) at the request of NAVSEA PMS 300, to evaluate the predicted roll characteristics on the Navy 65' PB MK III. Following this study, a task was authorized, reference (a), to obtain a 65' PB or similar craft for tests to determine the stabilization characteristics of a commercially available anti-roll fin system. Furthermore, since the ultimate use of the combatant craft is

as a weapons platform, a major part of this effort was to evaluate the effects of the active fin system on gun effectiveness. Specifically, the Naval Surface Weapons Center, Dahlgren (NSWC) was tasked to conduct tests simultaneously with NSND to determine this effectiveness. The results of those tests are presented in reference (b).

### Procedure

Initially, the tests were planned to be conducted with two like hull forms, one with an active fin roll stabilizer system installed and the motion characteristics of both craft could be measured at the same time in the same sea state and the results directly compared. Efforts were made to utilize two 20 knot plus craft in the Norfolk area, but operational commitments prohibited their use for this task. Two 65' Torpedo Retriever Boats (TRB) were made available in the Long Beach, California area (at the Naval Undersea Center) provided the fin system installation and required tests could be scheduled to suit their overhaul and operations schedule. Ultimately, the operational schedule prevented the use of both craft being tested simultaneously. The test program was modified to evaluate one boat with and without the fin system operational. To minimize the damping effects of the fins, they were allowed to free-stream in the "off" mode. The test craft has a design maximum speed of 18 knots, a speed considered to be marginally low for these tests since added appendage drag of the fins would reduce the maximum speed even further.

The tests were conducted in an area between five and fifteen miles offshore, due west of Long Beach Harbor. NSWC mounted a TV camera on the barrel of a 20 MM gun which was mounted midships on the starboard side of the boat. Various headings to the sea were run with NSWC personnel manually aiming the gun at "targets of opportunity". NSND personnel had instrumented the boat to measure and record craft roll and pitch angles, bow accelerations, vertical accelerations at the longitudinal center of gravity (LCG) and outboard vertical accelerations approximately at the gun location (see Figure 1). Sea State was measured with a Datawell "Waverider" buoy and recorded with the above parameters.

The active fin roll stabilization system was designed and built by Wilcox Marine Products, Incorporated, Ft. Lauderdale, Florida. Type 15A-5 Fin Integral System consisted of two self contained units mounted port and starboard and located 29'-2 1/2" forward of the transom and 6'-4" from the centerline at the point of hull penetration (see Figure 1). Each fin measured 30 inches (cord) by 24 inches (span) and had a maximum travel of  $\pm 26$  degrees. The fins were rectangular in planform and the fin stock axis was located 7 1/4 inches aft of the leading edge. The fin systems were mounted normal to the hull bottom resulting in the fin axis being 20 degrees off the vertical. The fins were manufactured of 3/8 inch steel plate coated with plastic resulting in a total thickness of 5/8 inches.

Fin operation was energized by an electrically powered hydraulic system that was in turn controlled by a roll rate sensing gyroscope located on the forward engine room bulkhead.

The Wilcox Marine roll stabilization system required considerably less time to check out and tune for satisfactory test operation than was experienced with the Sperry Rand-Vicker system that was installed on the Coastal Patrol Interdiction Craft. The Wilcox system is much simpler to install and operate, though maintenance could not be evaluated due to the limited operational test time.

### Results & Analysis

The craft roll angles and periods are presented in Figure 2. The data are presented for a craft speed of 14 knots at various headings to the sea with fins operating and free streaming. The statistical confidence of this data should be judged by the number of cycles tabulated. The roll amplitudes were either reduced or essentially unaffected depending on heading. What is significant was the large increase in roll period as can be seen in Figure 2. Obviously, the reduction of amplitude coupled with an increase in period have advantages when applied to a weapons platform.

The sea state data was obtained on a long continuous time basis and therefore a good statistical definition was obtained. Figure 3 contains the sea state information. In this case, wave frequency (Hz) is plotted against the sum of the squares of wave height in feet ( $\Sigma H^2$ ). From this it can be seen that there is an indication of two predominant frequencies indicating the existence of ground swells and superimposed wind generated waves. Included in Figure 3 is information to help in a comparison with the Naval Ship Research and Development Center's Sea State Description Chart developed by Wilbur Marks from which it is determined that there existed a Sea State 2 during the tests.

Roll motion decay tests were conducted both underway and at dockside with fin system deactivated. Figures 4a and 4b contain examples of oscillograph traces showing typical roll decay comparisons for both of the above conditions. It can be seen in Figure 4a that a hard chine craft, even at low speeds, is very stable due to the hydrodynamic forces on the hull. The craft is stabilized in only 2 cycles of roll. The third sample trace in Figure 4c is a dockside Roll Decay test for the second craft without the fin systems installed. Figure 5 compares the three above mentioned conditions with a plot of the angle of inclination versus the number of swings. It is apparent from this graph just how stable the craft is while underway.

Calculating the damping coefficients for these various conditions shows the order of magnitude of increased damping for the underway hard chine craft compared with the dockside (zero speed) condition. This degree of damping due to craft movement for the same forward speed increment has

been reported in reference (c) for a 165' patrol craft (PG) operating with an activated fin system. It is reasonable to conclude that with a hard chine planing configuration, the designer will achieve as much damping (roll reduction) due to hull form as can be obtained on larger displacement - round bilge configuration with active fin systems.

Furthermore, Figure 5 shows quantitatively the damping effects of the free streaming fin systems, a situation not totally unexpected. The dockside roll perturbations for both boats were induced by placing the two craft side by side and NSND personnel shifting weight from boat to boat at the natural roll frequency. Underway roll perturbations on the test craft were accomplished by manually manipulating the roll rate gyroscope at a rate close to the craft natural roll period.

Because of the relatively low speed of the test craft, the measured vertical linear accelerations were correspondingly low. For instance the maximum peak to peak readings of 0.6 g's were experienced at the bow location. Average accelerations regardless of heading or fin mode were around 0.2 g's at the longitudinal center of gravity (LCG) and at out-board craft locations. There was enough measurable difference to determine that the maximum accelerations occurred during the beam sea runs but this difference was rather insignificant. No slamming occurred during the tests so the nature of the accelerations experienced were of low amplitude and long time duration. Again, enough measurable difference was seen to determine a trend toward a very slight reduction of the g forces when the fin system was activated. Qualitatively, these acceleration force differences are not noticeable primarily due to their low values but another factor should be noted. The fin movement is not a smooth but rather a "stepped" movement. This motion appears to be characteristic of the Wilcox system. This stepping movement can be detected by on board personnel. It is also reflected in the pitch, roll and acceleration oscillograph traces and, as such, the frequency rate was determined to be around 3 CPS. The amplitude of these higher frequency accelerations induced by the fins is such that no discomfort was experienced. In fact, it is so slight that one generally has to be aware of this aspect of the fin operation to detect the disturbance. Overall, the accelerations experienced during these tests were not of major proportions and, hence, had little effect as regards crew efficiency or weapon effectiveness.

The active fin roll stabilizers are designed to reduce roll motion and velocity, the most uncomfortable sensations on most vessels. Their effect on pitch during this effort was immeasurable. Pitching, however, can have detrimental effects on weapon and crew effectiveness. Pitching during this test was not felt to be a major factor in effecting the results. Specifically, pitch excursions were fairly constant for all headings and fin modes with the maximum showing an occasional 4 degree peak to peak reading. The pitch period varied with heading with the minimum being about 1.9 seconds for the head sea condition and the maximum being about 4.9 seconds for the beam sea condition.

It is interesting to note that during several trial runs prior to the actual tests, the fins introduced air into the propellers when locked in position (pinned) due to the fins being slightly off center when locked, a condition corrected prior to the tests. It produced an underway list which would be expected but this situation was also corrected prior to tests. Because of the above conditions, it is strongly suspected that had higher speeds been attained the same air injection problem would exist with unlocked fins. Hence the ideal location of an anti-roll fin system on hard chine/high speed craft may be difficult to achieve.

### Conclusions

1. The active fin roll stabilization system either improved or had no effect on the roll amplitude and period for all conditions tested.
2. The active fin roll stabilization system significantly increased the roll period for all conditions tested.
3. Pitching motions were not measurably affected by the active fin roll stabilization operation as located on this craft for the conditions tested.
4. Acceleration forces were not of sufficient magnitude to have any great affect on crew effectiveness for the conditions tested.
5. No determinations have been made on active fin roll stabilization effectiveness on high speed/hard chine craft since the maximum speed of the test craft was limited to 14 knots. An analysis has been presented in the appendix to predict high speed effectiveness.
6. From the standpoint of ease of installation, air injection and righting moments, anti-roll fin systems are better suited for round bottom or double chine hull configurations.
7. Based on the roll damping data obtained, hard chine craft are very stable underway even at sub-planing speeds.
8. The Wilcox Marine Active Fin electronic control system was noted to be much simpler, more reliable, and easier to operate than other control systems of active fin systems with which NSND personnel are familiar.



TABLE SHOWING COMPARISON OF ROLL MOTIONS WITH AND WITHOUT ROLL STABILIZATION FINS ACTIVATED

HEADING	FIN MODE	ROLL IN DEGREES PEAK TO PEAK			AVG ROLL PERIOD (SEC)	NO. OF CYCLES OF DATA
		AVG	AVG 1/3 GREATEST	AVG 1/10 GREATEST		
BEAM	ON	5.8	9.0	11.3	7.3	5
BEAM	OFF	10.2	15.6	17.4	4.2	26
HEAD	ON	2.6	3.7	4.7	11.0	15
HEAD	OFF	2.4	3.5	4.7	5.2	22
BOW	ON	2.2	3.1	3.8	12.0	10
BOW	OFF	2.9	4.5	5.7	4.0	25

NOTES: (1) NSWL was tracking target for all above conditions but lost target during beam heading - fins off.

(2) Boat speed is approximately 14 knots.

Figure (2) - Table Showing Comparison of Roll Motions With and Without the Roll Stabilization Fins Activated

# SEA STATE MEASUREMENT RESULTS

AVERAGE WAVE HEIGHT	2.04 FT.
AVERAGE $\frac{1}{3}$ HIGHEST	2.93 FT.
AVERAGE $\frac{1}{10}$ HIGHEST	3.56 FT.
AVERAGE PERIOD	4.01 SECONDS

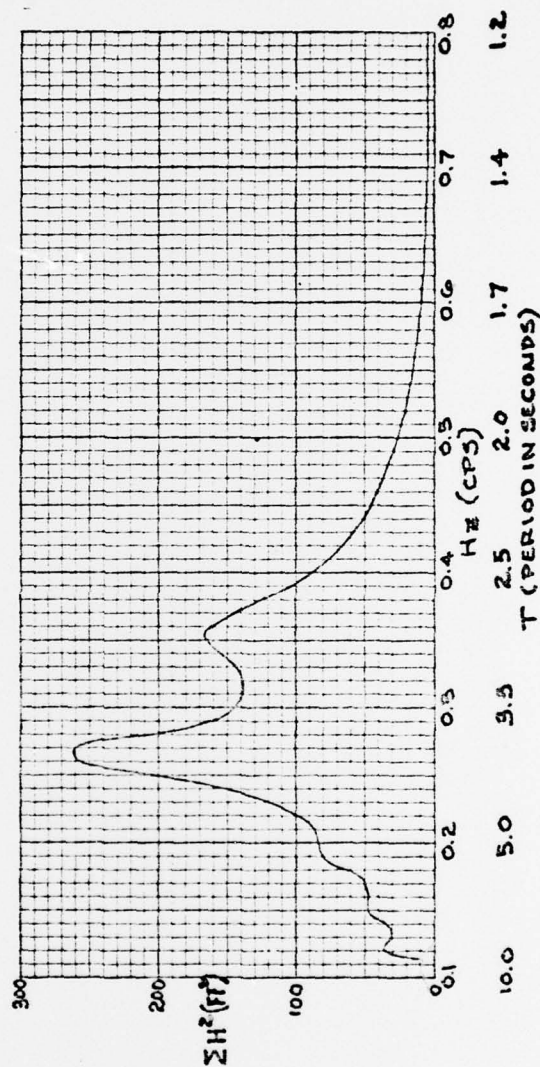


Figure (3) - Statistical Characteristics of the Measured Sea State

# ROLL DECAY TEST

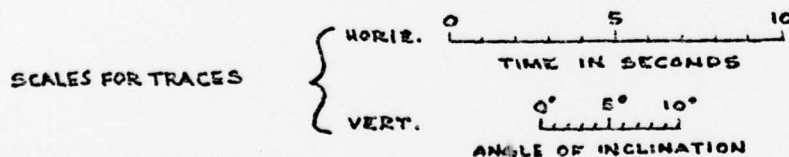
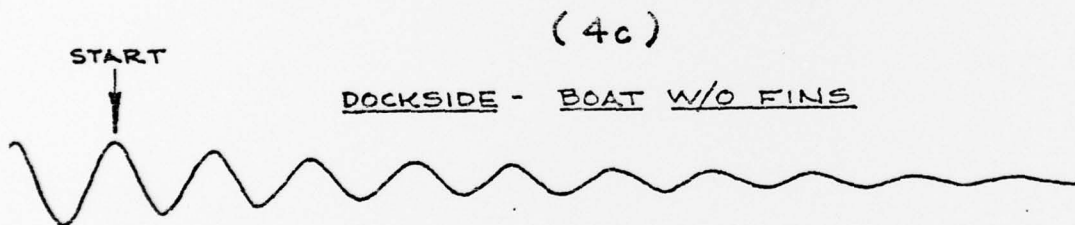
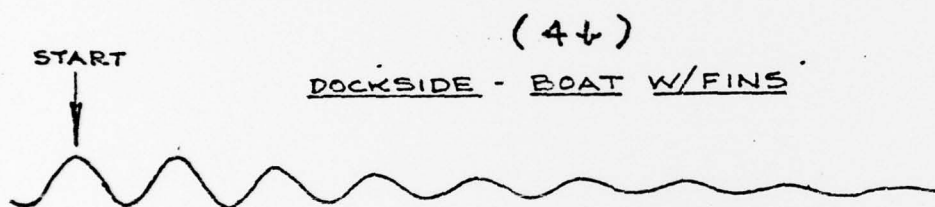
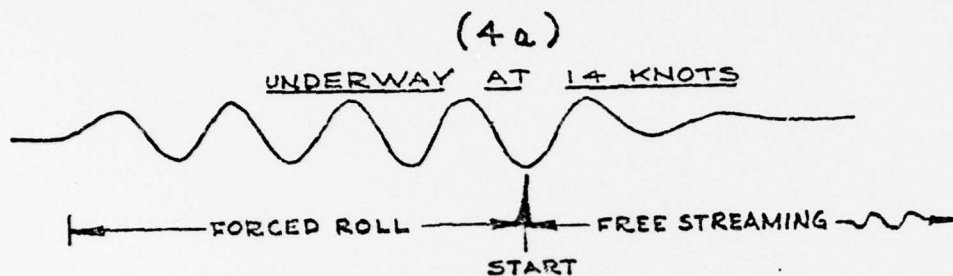
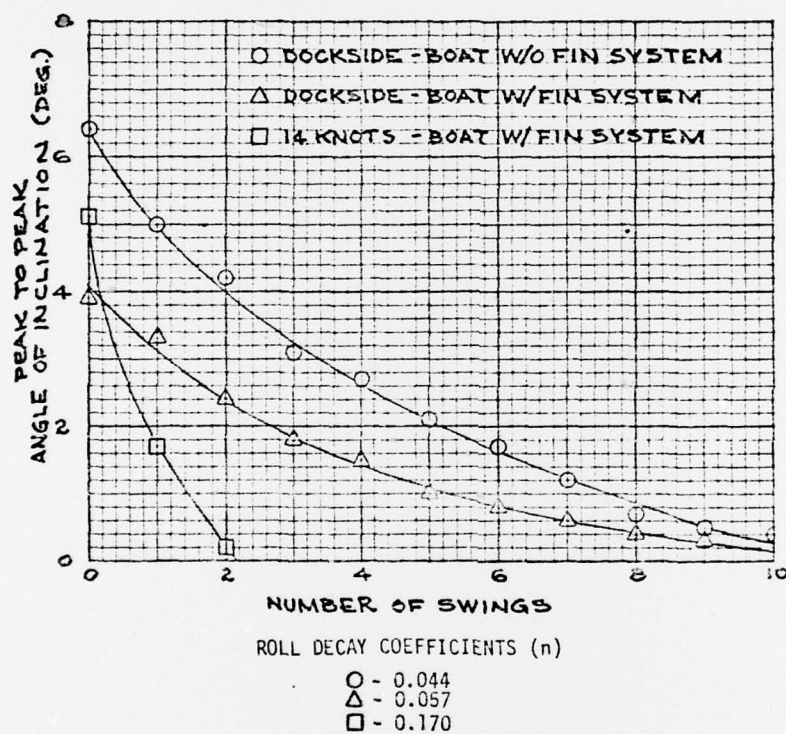


Figure (4) - Copies of Typical Oscillograph Traces Showing Samples of Roll Decay

## CURVES OF ROLL DECAY



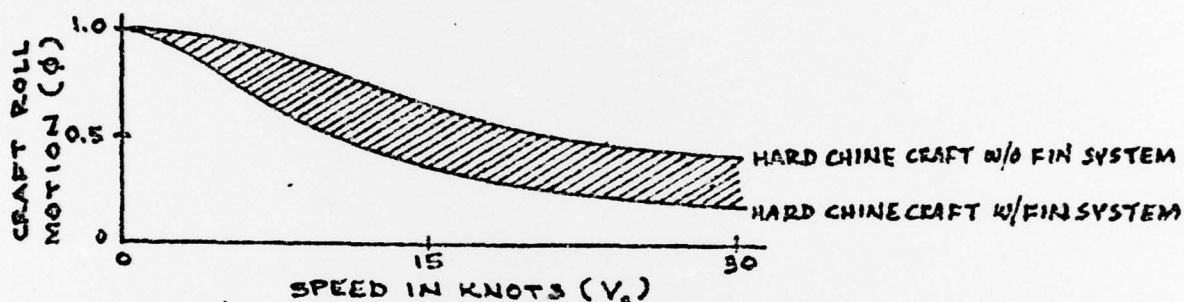
(n) can be calculated from the equation  $\ln \frac{A}{B} = 2\pi n$ ; where A and B are successive peak to peak values determined from the roll decay curve in calm water

Figure (5) - Curves of Roll Decay

## Appendix

### PREDICTION OF ROLL REDUCTION FOR HARD CHINE PLANING CRAFT AT HIGH SPEEDS WITH ACTIVE ROLL STABILIZING FINS

The damping tests were conducted with the fin system free streaming or deactivated. What cannot be presented is the effect on roll damping of activating the system with the craft underway. Test personnel are of the opinion that the craft would have stabilized in less than two cycles of roll at 14 knots had these tests been performed. The following illustration presents the major question in point:



Based on the results of this report, a significant improvement in roll motion and periodicity is realized in the intermediate speed range with hard chine craft. The question remaining is how much does the loop shown in the illustration close for the higher speed range? If there is adequate closure at high speed and the roll motion characteristics are acceptable in the intermediate speed range, then omitting the fin systems reduces the complexity of craft systems as well as cost and maintenance. Another question to address is the potential drag increment at high speeds on planing craft and the resulting effect on performance (speed and range).

In this appendix, the linear theory of Conolly, reference (d), is used to predict the reduction in roll due to the pair of active fins on the high speed, hard chine planing craft. It is assumed that the fins are so located on the craft, that they will be fully wetted at all speeds and will not ventilate causing a reduction in fin forces. To apply the Conolly theory it is necessary to obtain an expression for the stabilized roll angle ( $\phi_s$ ) divided by the unstabilized roll angle ( $\phi_u$ ) as a function of the craft and fin characteristics. As not all the required particulars are known, certain quantities must be assumed or estimated from existing data. The ratio of stabilized to unstabilized roll can be expressed by the equation, reference (e),

$$\phi_s/\phi_u = \left[ 1 + \frac{\rho A_F R_F W_\phi}{2\Delta GM} \left( \frac{\partial C_L}{\partial \beta} \right) \frac{V^2}{n} k_2 \right]^{-1} \quad (1)$$

where  $\rho$  is the mass density of water, 1.99 slugs/ft<sup>3</sup>

$A_F$  is fin area per side of craft in square feet

$R_F$  is distance from the center of pressure of the fin to the roll axis in feet

$W_\phi$  is the natural frequency of roll in radian per second

$\Delta$  is craft displacement in pounds

$GM$  is metacentric height in feet

$\frac{\partial C_L}{\partial \beta}$

is slope of lift coefficient curve per radian of fin angle

$V$  is craft speed in feet per second

$n$  is the roll-decay coefficient

$k_2$  is a control characteristic of the system

It is assumed that the fin lift coefficient  $C_L$  is linearly proportional to the fin angle  $\beta$  so that the slope of the lift coefficient curve can be expressed by the equation, reference (e)

$$\frac{\partial C_L}{\partial \beta} = 5.65 (2 AR) \left[ \sqrt{(2 AR)^2 + 4} + 1.8 \right]^{-1} \quad (2)$$

where  $AR$  is the fin aspect ratio

$$\frac{\partial C_L}{\partial \beta} = 2.07 \text{ per radians of fin angle}$$

It is assumed that complete roll decay occurred in 1 1/2 cycles of roll with the fins activated during the damping tests. Calculating  $(n)$  from the equation shown earlier gives a value of 0.30.

$(k_2)$  can be calculated from equation (1) and the test results at 14 knots knowing  $(\phi_s/\phi_u)$  and using  $n = 0.30$ ; then  $(k_2) = 1.2$ .

Finally  $(\phi_s/\phi_u)$  can be calculated for 30 knots, assuming that  $(k_2)$  does not change, which is reasonable, and using a value of 0.30 for  $(n)$ , which is conservative for in all likelihood it will increase at the higher craft speeds, then  $(\phi_s/\phi_u) = 0.22$ .

This can be interpreted as predicting a roll motion reduction of 75 to 80 percent at these higher craft speeds with the increase in hull damping. Examining the linear equation (1), the roll attenuation is mostly effected by the craft speed squared ( $V^2$ ) and not the hull damping term  $(n)$ .

It is concluded by this prediction that significant improvement on craft roll amplitude could be expected. The prediction method does not address heading to the sea although a beam sea is implied and no attempt is made to predict roll period. In practice certain hydrodynamic factors and hull geometry would be influential to successful operation for the subject hardware. On a hard chine/high speed craft fin venting and/or cavitation would surely occur thus limiting or possibly eliminating a workable location due to fin/propeller interaction. On the other hand if the trend of future hull designs is going to the high length/beam ratios (such as CPIC) then further studies should be conducted since this hull form is geometrically better suited for the hull/fin combination.

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